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High repetition rate Q-switched Er^{3+}-doped fiber ring laser

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Introduction: Er^{3+}-doped fibers have been subject to an intensive research and development for optical amplifiers and lasers of CW & pulsed operation [1]-[3]. Q-switched fiber lasers can be used to generate pulses with very high peak power and narrow pulsewidth with applications in nonlinear optics, sensing, communication, laser ranging, and in microsurgery [4]. The advantages of the fiber lasers are: easy coupling to the application systems, laser diode pumping, compact size, and excellent energy dissipation.

In this paper we present the first Q-switched fiber laser utilizing a ring cavity. So far, in order to obtain short cavity lifetime, the Q-switched fiber lasers have been reported only in a Fabry-Perot cavity.

Theoretical investigations have been carried out for the Q-switched F-P fiber lasers [5]. These are, however, not suitable to our configuration because of our long cavity compared to the pulsewidth and because a substantial part of the cavity length consist of passive fiber. Consequently, the cavity roundtrip time is larger than the pulsewidth and the pulse is actually located inside the cavity. To incorporate this assumption into a model, a careful characterization of all the applied components used must be carried out.

Experiment and discussion: The experimental setup is shown in Fig. 1. An Ar^+ laser pumped Ti:Sapphire laser at 980 nm is used to pump the Er^{3+}-doped fiber. The pump light is coupled into the ring cavity through the wavelength division multiplexer. Erbium doped fiber co-doped with Aluminum and Lanthanum has a core diameter of 3.5 μm, a NA of 0.23 and cut-off wavelength of 1200 nm. The erbium concentration is measured to be 2.1×10^{25} m^{-3} with a florescent lifetime of 11.4 ms.

A 3 dB output coupler is found to give an optimum output. The nonspliced arms are equipped with angled connectors to assure minimum back reflection into the configuration. The Q-switching element in the ring cavity is an pigtailed Acousto-Optic (A/O) loss modulator utilizing a $LiNbO_3$ crystal. High extinction ratio of 30 dB of the low-Q and high-Q regimes is obtained by using the first order diffracted light coupled into a fiber-pigtailed output. Minimum loss of the A/O-modulator is measured to be 8 dB at $\lambda = 1556$ nm. When the modulator is driven by a square electrical signal with a frequency of 400 Hz, the risetime of the generated optical signal is 25 ns. Traveling wave operation is accomplished by the low loss and polarization insensitive isolator. The roundtrip loss of the cavity without the erbium doped fiber and output coupler at $\lambda = 1556$ nm is 11 dB.

A Q-switched pulse, obtained at the modulation frequency of 400 Hz and the pump power of 200 mW, is shown in Fig. 2. The structure of the pulse is in agreement with our model prediction and consists of several highly distinguishable peaks, spaced by the roundtrip time of the cavity. One of the peaks dominate over the others resulting in a FWHM of 12 ns and a peak power of 340 W. Overall length of the cavity is 6.8 m corresponding to the time difference of the pulse components of 33 ns. In order to improve the performance of the laser, a short length of a new, higher doped Er^{3+}-doped fiber has been used. In spite of the shorter cavity lifetime, this configuration yielded a poor laser performance.

The measured peak power and pulse width of the Q-switched pulse are shown in Fig.3, as function of the length of the Er^{3+}-doped fiber. The performance of the laser has a relative sharp drop for doped fibers shorter than 1.5 m. This is caused by a large increase in the threshold as observed in [2].

The peak power and pulse width of the Q-switched pulse are shown in Fig.4. as a function of the modulation frequency of the A/O-modulator. Stable Q-switching exists up to 100 kHz of modulation frequency. Peak power and pulse width at 100 kHz are 8 W and 136 ns respectively. Beyond this limit the laser is unstable with a tendency to build up pulses with repetition rate equal to half of the modulation frequency. Unlike in [1], it has not been possible to stabilize the Q-switched operation with a higher order repetition rate by further increase of the modulation frequency.

Conclusion: Performance of the Q-switched fiber ring laser with pigtailed A/O intensity modulator is analyzed as a function of doped fiber length and modulation frequency of the modulator. Peak power of 340 W with pulsewidth of 12 ns is achieved. Stable Q-switched operation extended up to 100 kHz with 8 W peak power is observed.

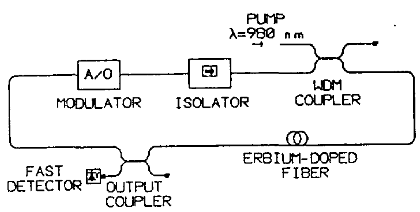

Fig.1 Experimental configuration of the Q-switched Er^{3+}-doped fiber ring laser.

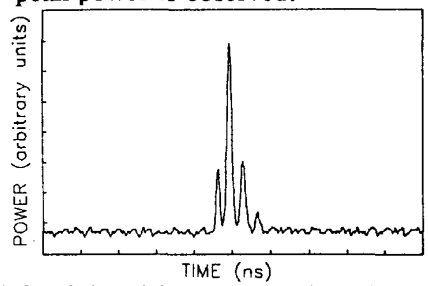

Fig.2 Typical Q-switched pulse measured at modulation frequency of 400 Hz, pump power of 200 mW at 980 nm Duration of the pulse (FWHM) is 12 ns with peak power of 340 W.

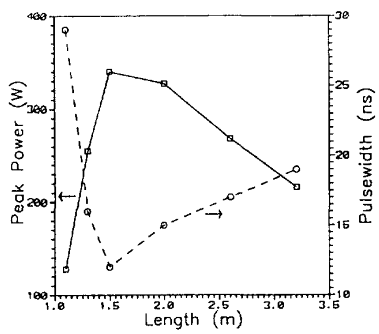

Fig.3 Peak power and pulsewidth as function of the length of the active fiber. Both curves are measured at pump power of 200 mW and modulation frequency of 400 Hz.

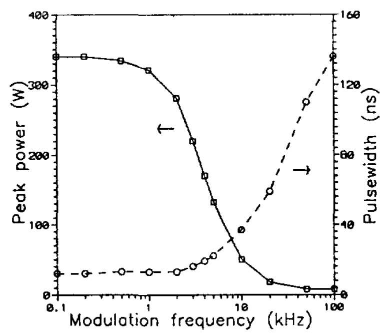

Fig.4 Peak power and pulsewidth as function of modulation frequency. Both curves are measured at pump power of 200 mW and length of the active fiber of 1.5 m.

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